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Seongwan Park
The CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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SEARCH FOR SECOND GENERATION LEPTOQUARKS AT CDF

SEONGWAN PARK*
Fermi National Accelerator Laboratory,
P.O.Box 500, Batavia,
Illinois 60510, USA

ABSTRACT

We present the results of a search for second generation leptoquarks $\mathcal{S}_2$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron. This search is based on 19.3 pb^{-1} of data collected during the 1992–93 CDF run. We have searched for evidence of leptoquark pairs assuming that each leptoquark decays to a muon+quark with a branching ratio β. Two leptoquark candidate events were found with a background of 1.35 ± 0.50. We obtained upper limits on the production cross-section times branching ratio as a function of leptoquark mass. For pair production of second generation leptoquarks, we excluded $M_{\mathcal{S}_2} < 133$ GeV/c^2 for $\beta = 100\%$ and $M_{\mathcal{S}_2} < 98$ GeV/c^2 for $\beta = 50\%$ at 95% CL.

1. Introduction

Leptoquarks which carry both color and lepton quantum numbers appear in many extensions to the standard model that connect the quark and lepton sectors.[1] A leptoquark is fractionally charged and decays directly to a quark-lepton pair of the corresponding generation.[2] A second generation leptoquark $\mathcal{S}_2$ is assumed to decay to a muon+quark with branching ratio β, or to a muon neutrino+quark with branching ratio $1-\beta$.

In this analysis, we are looking for a second generation leptoquark $\mathcal{S}_2$ with the CDF detector at the Fermilab Tevatron $p\bar{p}$ collider at $\sqrt{s} = 1.8$ TeV. There is no reported search of second generation leptoquarks in $p\bar{p}$ collisions, and the only published mass limit of 44.2 GeV/c^2 independent of β comes from LEP searches.[3] For first generation leptoquarks, DØ reported the limits of 133 GeV/c^2 for $\beta = 1$ and 120 GeV/c^2 for $\beta = 0.5$,[4] and searches at HERA have ruled out first generation leptoquarks up to $\simeq 180$ GeV/c^2 assuming the unknown Yukawa coupling $\mathcal{S}_2$-q-l is the same as the electroweak coupling.[5]

This analysis is based on 19.3 ± 0.7 pb^{-1} of data collected during the 1992–93 Tevatron run. In $p\bar{p}$ collisions, $\mathcal{S}_2\bar{\mathcal{S}}_2$ pairs can be produced through $O(\alpha_s^2)$ processes, $q\bar{q}$ annihilation and gluon-gluon fusion, whose rates are independent of the unknown Yukawa coupling. We have searched for $\mathcal{S}_2\bar{\mathcal{S}}_2$ pairs in the decay channel where both leptoquarks decay to a muon+quark, thus we expect a dimuon+dijet signature with rate β^2.

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*Representing the CDF Collaboration.

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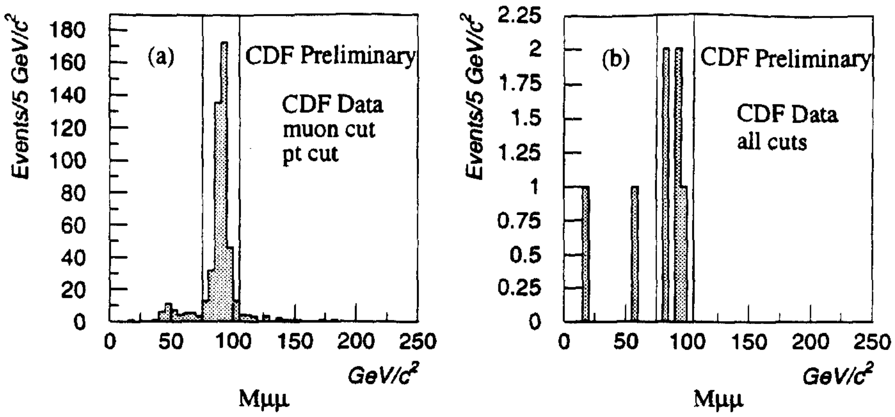

Fig. 1. Dimuon invariant mass distributions. (a) CDF dimuon data after muon cuts, p_T cut and opposite charge cut applied. (b) CDF dimuon data after all cuts are applied except Z removal. Vertical lines indicate Z mass window.

The CDF detector has been described in detail elsewhere.[6] We give a brief description of the components relevant to this analysis. The momenta of charged particles are measured in the central tracking chamber (CTC), which is surrounded by a 1.4 T superconducting solenoidal magnet. Outside the CTC, electromagnetic and hadronic calorimeters, arranged in a projective tower geometry, cover the pseudorapidity region $|\eta| < 3.6$. The calorimeters are used to identify jets. Outside the calorimeters, drift chambers in the region $|\eta| < 1.0$ provide muon identification. A three-level trigger selects the inclusive muon events used in this analysis.

2. Leptoquark Search

To select second generation leptoquark candidate events in dimuon+dijet channel, at least one of the muons is required to have $|\eta| < 1.0$ and to be isolated.[6] The second muon can be a minimum ionizing particle identified by CTC and calorimeters within $|\eta| < 1.2$.[6] Both mùons are required to have $p_T > 20\,\text{GeV}/c$ and to have opposite charges. After these cuts, we have 480 dimuon events. We further require that the azimuthal angle between two muons is smaller than 160°and that two 20 GeV jets in the region $|\eta| < 3.5$. After these cuts, 7 events are left. To remove background from Z production, we reject events with $75 < M_{\mu\mu} < 105\,\text{GeV}/c^2$. Five events are consistent with Z+two jets. Figure 1 shows the dimuon invariant mass distributions.

Two events remain after removing the Z candidates, and a schematic transverse plane view of them is shown in Fig. 2. The labels for leptoquarks, muons and jets are determined by choosing the combination which gives smaller difference in leptoquark masses reconstructed from muon and jet momenta. In this manner, we derived the masses of the leptoquark pairs to be 51.0 and $92.0\,\text{GeV}/c^2$ for the first candidate event, and 68.3 and $67.0\,\text{GeV}/c^2$ for the second. The estimated resolution of the muon+jet mass is about $13\,\text{GeV}/c^2$ for $100\,\text{GeV}/c^2$ leptoquarks. The dimuon invariant masses of both candidates are $18.9\,\text{GeV}/c^2$ and $57.9\,\text{GeV}/c^2$, and well below the lower Z mass

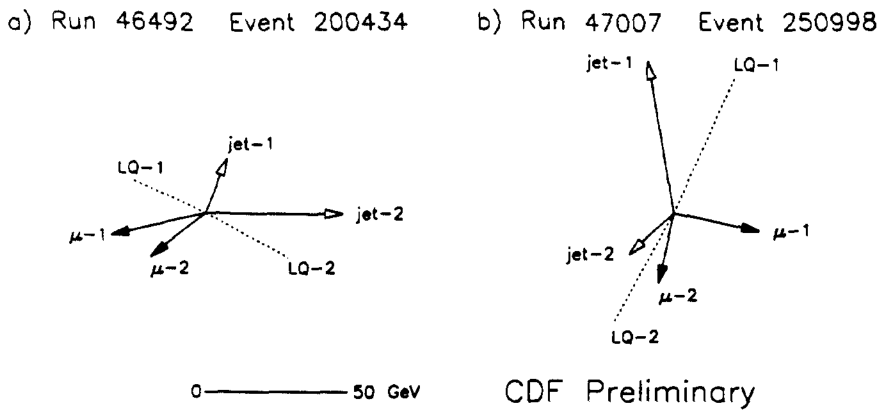

Fig. 2. Display of kinematics of candidate events. The lines show momentum vectors of the objects in a transverse view. (a) Run 46492 Event 200434, (b) Run 47007 Event 250998.

cut.

To determine the signal detection efficiencies, we use the ISAJET[7] Monte Carlo program with CTEQ2L[8] structure functions, followed by a CDF detector simulation. The combined efficiency ranges from 1.2% for $40\,\mathrm{GeV}/c^2$ leptoquarks to 16.8% for $200\,\mathrm{GeV}/c^2$, and is 12.5% for $120\,\mathrm{GeV}/c^2$. The fractional uncertainty on the overall efficiency ranges from 52.2% for $40\,\mathrm{GeV}/c^2$ leptoquarks to 11.6% for $200\,\mathrm{GeV}/c^2$, and is 12.1% for $120\,\mathrm{GeV}/c^2$. It includes the uncertainty due to the limited understanding of gluon radiation which ranges from 47.4% to 8.5% for $40\,\mathrm{GeV}/c^2$ to $200\,\mathrm{GeV}/c^2$ and is 7.8% for $120\,\mathrm{GeV}/c^2$, and the uncertainty due to jet energy scale which ranges from 17.5% to 3.0% for $40\,\mathrm{GeV}/c^2$ to $200\,\mathrm{GeV}/c^2$, and 5.4% for $120\,\mathrm{GeV}/c^2$. These two are the dominant sources of the uncertainty for low mass leptoquarks. Other uncertainties come from the structure function choice (6.2% to 0.3% for 40 to $200\,\mathrm{GeV}/c^2$ and 1.1% for $120\,\mathrm{GeV}/c^2$), Monte Carlo statistics (8.8% to 2.2% for 40 to $200\,\mathrm{GeV}/c^2$ and 2.6% for 120 GeV/c^2), detector simulation (6%), and luminosity measurement (3.5%).

Any physical process producing two muons and two jets with high p_T or E_T can be a background. The main backgrounds are Drell-Yan production of muon pairs with two jets (0.73 ± 0.37 derived from Z+2jet events) and $t\bar{t}$ production in dimuon channels (0.45 ± 0.16 using the recently published $t\bar{t}$ cross-section $13.9^{+6.1}_{-4.8}$ pb by the CDF collaboration[9]). Other backgrounds are $Z \rightarrow \tau^+\tau^-(0.12 \pm 0.03)$ and hadrons misidentified as muons (0.05 ± 0.04). The backgrounds due to $b\bar{b}$ and WW are negligible. The total expected background is 1.35 ± 0.50 events.

3. Results

We observed two candidate events consistent with the total background of 1.35 ± 0.50 events. The 95% CL limits on the cross-section times branching ratio[10] are shown in Fig. 3 with a theoretical prediction of the cross-section times branching ratio for $\beta = 1$. The prediction is based on ISAJET[7] with CTEQ2L structure function.[8] We also obtain limits for the leptoquark mass as a function of β which are shown in Fig. 3.

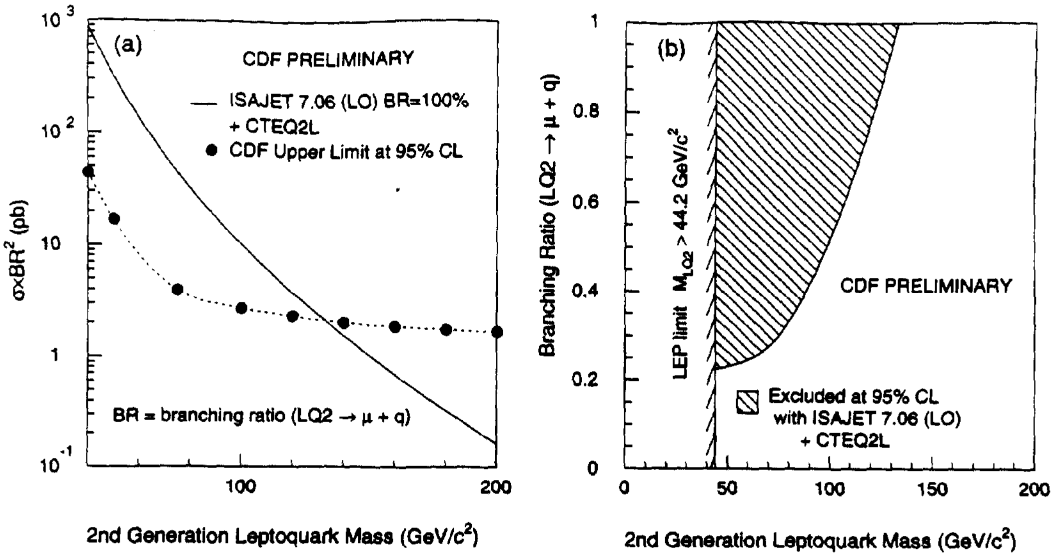

Fig. 3. (a) 95% CL upper limit on $\sigma(M_{S_2}) \cdot \beta^2$ as a function of second generation leptoquark S_2 mass. (b) 95% CL limit on β as a function of second generation leptoquark mass.

The 95% CL lower limit on the mass of a second generation leptoquark for $\beta = 1$ is $133\,\mathrm{GeV}/c^2$, and the lower limit for $\beta = 0.5$ is $98\,\mathrm{GeV}/c^2$.

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